Patterns of osmoregulation

There are two basic strategies for the pattern of osmotic concentration (and ionic concentrations) in animals, conforming or regulating.

- Some animals are isoosmotic to their environment i.e. osmoconform
- Other animals are either hypo-osmotic or hyper-osmotic i.e. osmoregulate

1

Osmo and Iono Regulation

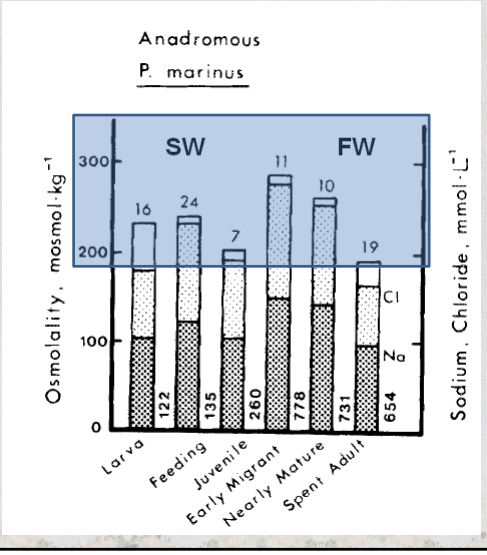
VERTEBRATES

"primitive SW?"
"or returned to SW from FW"

Species	Osmotic concentration (mOsm)	mM Na	K	Ca	Mg	Cl	Urea	TMAO
Agnatha								
Myxine (hagfish)	1 062	558	10	6	18	546	–	–

2

The lamprey is an osmoregulator and ionoregulator. “Advanced”.



3

Osmo and Iono Regulation

VERTEBRATES

Species	Osmotic concentration (mOsm)	mM Na	K	Ca	Mg	Cl	Urea	TMAO
Agnatha								
Myxine (hagfish)	1 062	558	10	6	18	546	–	–
Petromyzon (lamprey)	317							
Chondrichthyes (elasmobranchs)								
Mustelus (dogfish)	1 011	288	8	5	3	270	342	~100
Raja (ray)	1 050	289	4				444	
Osteichthyes								
Latimeria (coelacanth)	1 181	181	51	4	14	200	355	~100
Teleosts								
Lophius (anglerfish)	452	180	5	3	3	196	<1	–
Opsanus (toadfish)	392	160	5				<1	–
Anguilla (eel, in sea water)	371	177	3				<1	–
Gadus (cod)	308	174	6	7	3	150	<1	–
Amphibia								
Rana cancrivora (crab-eating frog)	830	252	14				350	

TMAO, trimethylamine oxide.

“primitive SW?”
“advanced”
“returned to SW”
“advanced”
“returned to SW”

4

Marine elasmobranchs, coelacanth (and crab-eating frog) “returned to SW”?

Component	Osmotic concentration (mOsm)	mM Na	K	Ca	Mg	Cl	Urea + TMAO
Blood/ECF	1096	296	7	3	4	276	504
Intracellular (muscle)	1189	18	130	2	14	13	905
Rectal gland fluid	1050	512	3	1	3	520	–

ECF, extracellular fluid; TMAO, trimethylamine oxide.

Ureo-osmoconform/Ionoregulate

High salt concentrations disrupt proteins

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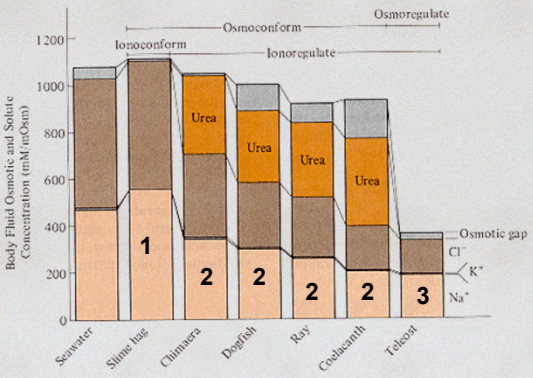
3. Osmo- and Iono-Regulation

Freshwater teleosts



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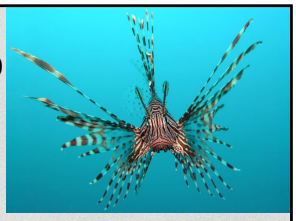
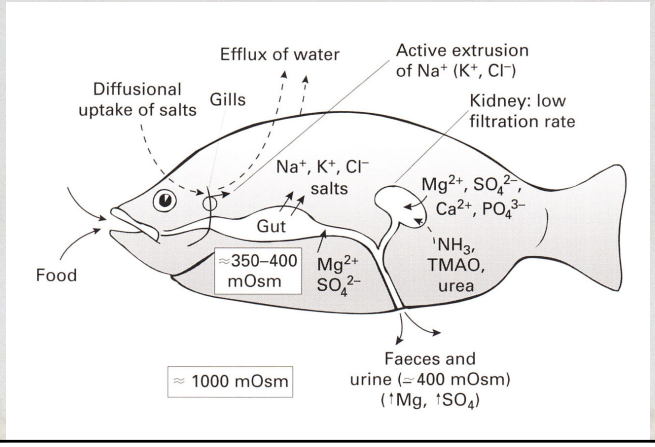
Teleosts – osmoregulate and io



Osmo and Iono regulation produces a problem:

Needs to reduce urine concentration and have salt pumps on gills



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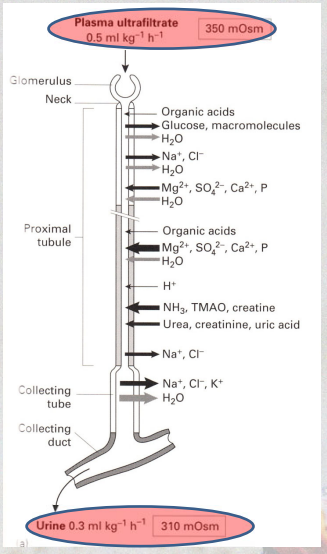
Osmo and Iono Regulation

Marine Teleosts – kidneys have many simple/complex functions

Solute regulation

Minimal water loss (low filtration and urine flow)



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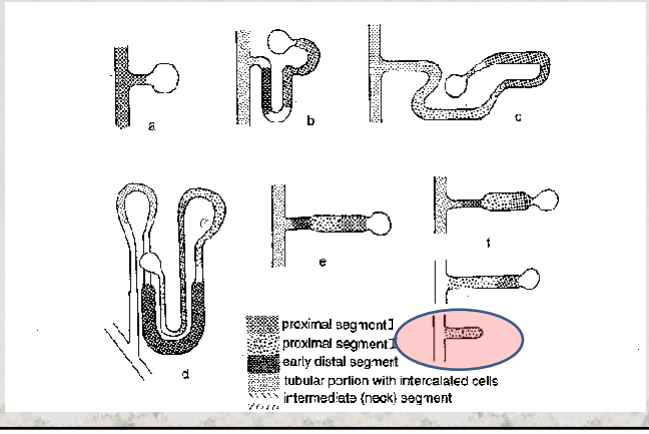
Aglomerular kidneys

Some marine fishes have aglomerular nephrons to minimise urine flow rate and avoid excretion of antifreeze proteins!



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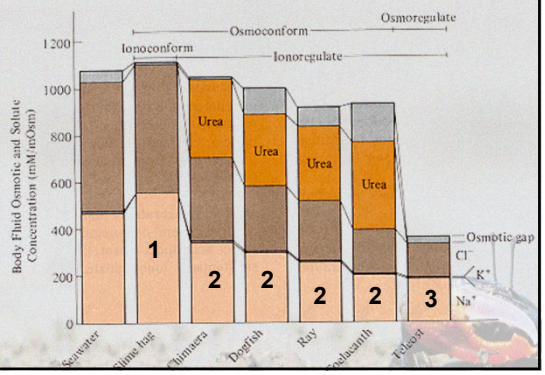
Secondary Marine Invasions – same problem, different solutions

All marine vertebrates? (SW or FW origins?)

Probably FW or brackish water and perhaps anadromous (FW -> SW -> FW) or
catadromous (SW -> FW -> SW)

Three possible strategies

1. Revert to osmo/iono-conforming (hagfish?)
2. Revert to osmoconform but iono-regulate (sharks)
3. Retain osmo/iono-regulation (bony fishes)



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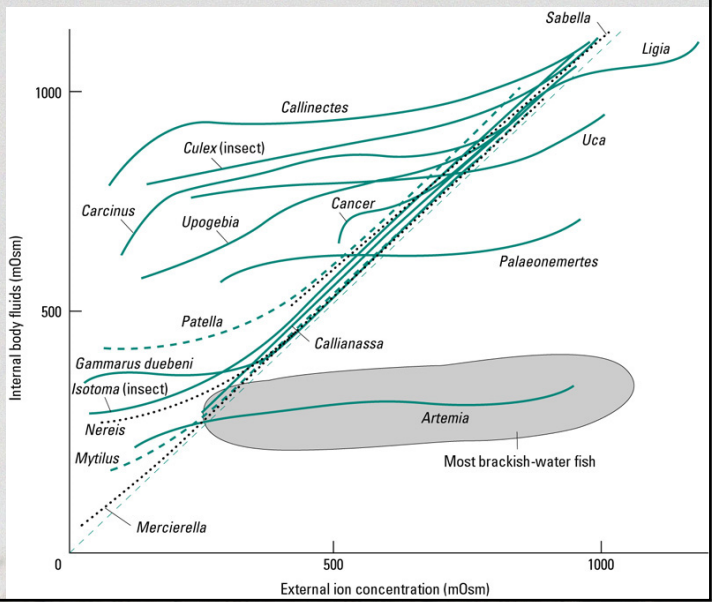
Conformers vs regulators

- Few hyporegulators
- Some perfect conformers
- No perfect regulators



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Urea presents a problem for going back to freshwater

Freshwater (not very!) shark Carcharhinus

Table 1. Chemical composition (millimoles per liter) of serums of sharks

Item	*C. leucas leucas*	*C. leucas nicaraguensis*
Ions:		
Na	223.4	200.12
K	9.0	8.2*
Ca	4.5	3.0
Mg	2.9	2.0
Cl	236.0	180.5
HCO_3	5.1	6.0
SO_4	0.6	0.5
PO_4	2.0	4.0*
Total	483.5	404.3
Urea nitrogen	333.0	132.0
Ultrafilterable Ca	3.7	1.8
Protein (g %)	2.4	3.4
Alkaline phosphatase	0.9	3.0
Acid phosphatase	1.0	1.1

*Hemolyzed blood.

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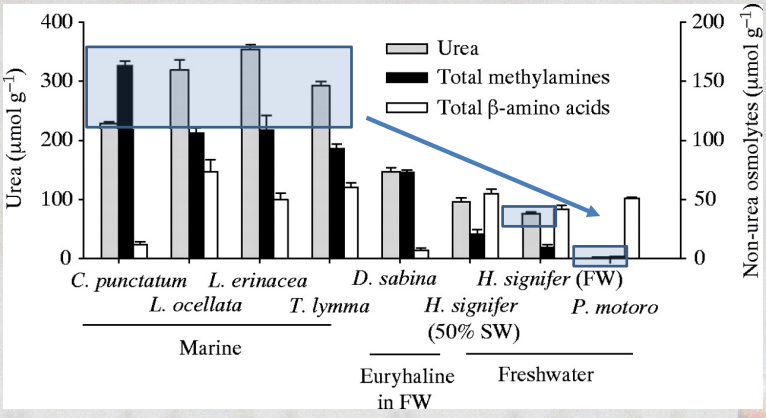
Freshwater (very!) rays



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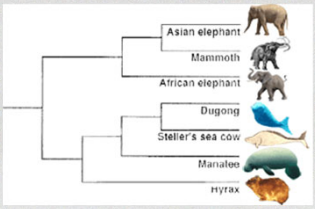
Secondary Land -> Marine Invasions

Marine mammals

- Cetaceans (artiodactyls)
- Pinnipeds (carnivores)
- Dugong/Manatee (Afrotheria)



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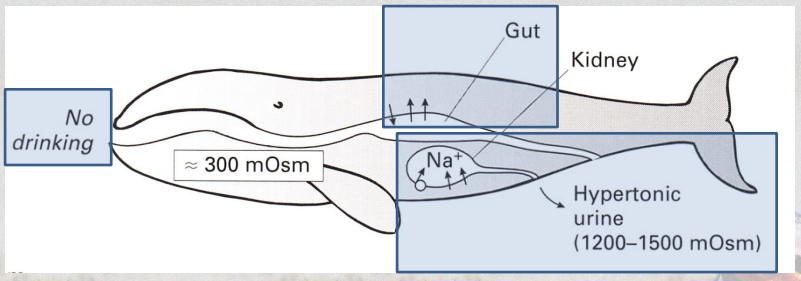
Osmo and Iono Regulation

Marine mammals

- Can drink seawater (but usually don't need to)
- Food is important – meat vs crustaceans
- Gut deals with divalent cations e.g. Mg^{2+}, $SO4^{2-}$
- Kidneys concentrate urine NaCl and urea



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Marine birds – semi-aquatic (like seals)

Penguins

Various other marine birds

Avian kidney can hyper-concentrate urine but not as well as mammals

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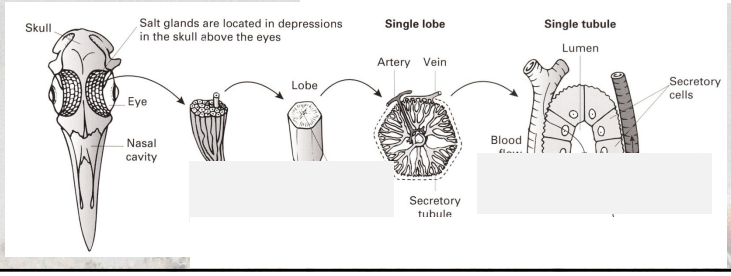
Reptiles and Birds salt glands

Table 9.11 Salt gland performance in marine tetrapods.

Species	Na^+ concentration (mM)	Flow rate ($\mu l\ kg^{-1}\ h^{-1}$)
Sea snake	620	35
Terrapin	680	4
Turtle	690	19
Marine iguana	1000–1400	8
Cormorant	500–600	70
Pelican	600–750	100
Gull	600–900	30
Penguin	720–850	40–70
Petrel	900–1100	–